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Magnetic Properties of the Electron-Doped Superconductor $Nd_{2-x}Ce_xCuO_{4-\delta}$

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Magnetic Properties of the Electron-Doped Superconductor $Nd_{2-x}Ce_xCuO_{4-\delta}$

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Abstract

Magnetic susceptibility and magnetization data are presented for $Nd_{2-x}Ce_xCuO_{4-\delta}$ system. The Nd-local moments are seen to be crucial in interpreting the magnetic response. Evidence for a pervasive diamagnetic component (onsetting near 24K) in the low fieid response which is sharply maximized near x=0.16 is presented.

Key words: Electron-Doped Superconductor, Diamagnetic, Hystersis Loop

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Strong evidence for n-type charge carriers which dwell (at least partially) on the Cu sites, has been presented for the $Nd_{2-x}Ce_xCuO_{4-\delta}$ high T_c system[1-3]. This is significant in that it provides the first indication that the disappearance of Cu-magnetism and appearance of superconductivity may occur symmetrically[4,5] as one moves away from Cu^{II} toward Cu^{III} (hole donation) or toward Cu^{I} (electron donation). Here we present a series of magnetic measurements on this important material which emphasize the role of the Nd magnetic moments and, more importantly, which show the singular fashion in which superconductivity occurrs in these alloys.

The sample preparation procedures have been described elsewhere[3]. The magnetic measurements were performed on a superconducting quantum interference device (SQUID) magnetometer.

The magnetic susceptibility (χ) and χ^{-1} of an x=0.075 material is shown in figure 1. Above 80K typical Nd^{3+} full moment behavior is observed with $\chi(T) \approx C/(T+\theta)$, θ=56K and C=3.014 emu K/mole. This Curie constant corresponds to $\mu_{eff}=3.54\mu_B$/Nd and is very close to the full Nd^{3+} value in it's $^4I_{9/2}$ Hund's rule ground state. Below 50K a decrease in the effective moment [as expected from crystalline electric field (CEF) effects typical to Nd systems[6]] is clear, from the curvature of the $\chi^{-1}(T)$ curve. We note that a broad but modest anomaly in the susceptibility between 320-365K was observed in some materials with x=0.075. A similar anomaly has been associated by Tarescon et al. [7] with the onset of antiferromagnetic order in the Cu-planes for the x=0.0 material.

In the $5 \leq T \leq 25K$ range the magnetic susceptibility (at 10KOe) can be fit with $\theta = 5.2K$ and the CEF reduced moment of $\mu_{eff} = 2.33 \mu_B$/Nd (see inset of figure 1 for the χ^{-1} data). Lower field measurements of the susceptibility however reveal an anomalous diamagnetic deviation from this Curie Weiss law onsetting at 24K. A small drop from the overall background semiconducting resistivity can also be observed at 24K. Thus superconducting material is present (albeit at quite low levels) even in this x=0.075 material.

In figure 2 we show low field susceptibility measurements, taken in the Meissner mode for a series of samples in this series. The presence of diamagnetic signals can be discerned in all of these samples however the magnitude of the signal exhibits a sharp maximum near x=0.16 (see inset). Both the resistive and magnetic signatures of superconductivity in this series appear to exhibit an onset temperatures always near 24K. All of these materials possess at least two types of site defects, the Ce substitute and oxygen vacancies[8,9] (believed to occur at the $\delta = 0.04$ level). Inhomogeneity Fluctuations in the compositions and correlations between those defects must occur in these materials. It would appear that superconductivity is sharply optimized with ($T_c = 24K$) for a sharp defect composition/correlation in these materials. Apparently the Ce-composition contribution to this optimization lies very close to x=0.16.

In figure 3 we show the hystersis loop for $Nd_{1.85}Ce_{0.15}CuO_{4-\delta}$ sample. The M vs. H curve starts to deviate from linearity at $H_{c1} \sim 300$ Oe, similar to what has been observed for the hole-doped $La_{1.85}Sr_{0.15}CuO_4$. H_{c1} here is the field above which the first flux thread start to enter the superconducting grains in the materials. The magnetization becomes essentially reversible

for H > 20kOe. At higher fields the diamagnetic fraction is slowly reduced while the background exhibits a large and nonlinear paramagnetic local moment behavior. To qualitatively illustrate the background we show the M(H)curves for the full Nd moments and for a reduced effective $J_{eff}=3.32$ (derived from the CEF reduced $\mu_{eff}=2.33\mu B$ of our susceptibility results). ←
The presence of significant diamagnetic signal even at 50kOe is consistent with the much larger H_{c2} values reported for H along the c-axis[10].

Our work underscores the need to identify the microscopic electronic/structural parameters which support the narrow-range superconductivity in these materials. Moreover separation of the Nd-local moment response is also needed to better elucidate the superconductivity properties.

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Figure Captions

Figure 1. The temperature dependence of the magnetic susceptibility (χ) and its inverse (χ^{-1}) for $Nd_{2-x}Ce_xCuO_{4-\delta}$, x=0.075. Inset low temperature χ^{-1} data at various fields illustrating the diamagnetic signal onsetting near 24K.

Figure 2. Meissner mode results for magnetic susceptibility at various x-values in the $Nd_{2-x}Ce_xCuO_{4-\delta}$ system. Inset the diamagnetic fraction $-4\pi\chi$ versus x.

Figure 3. Magnetization M versus field H curves for an x=0.15 sample illustrating the superconducting hysterysis loop, the behavior near H_{c1} (inset lower right) and the high field behavior (inset upper left).

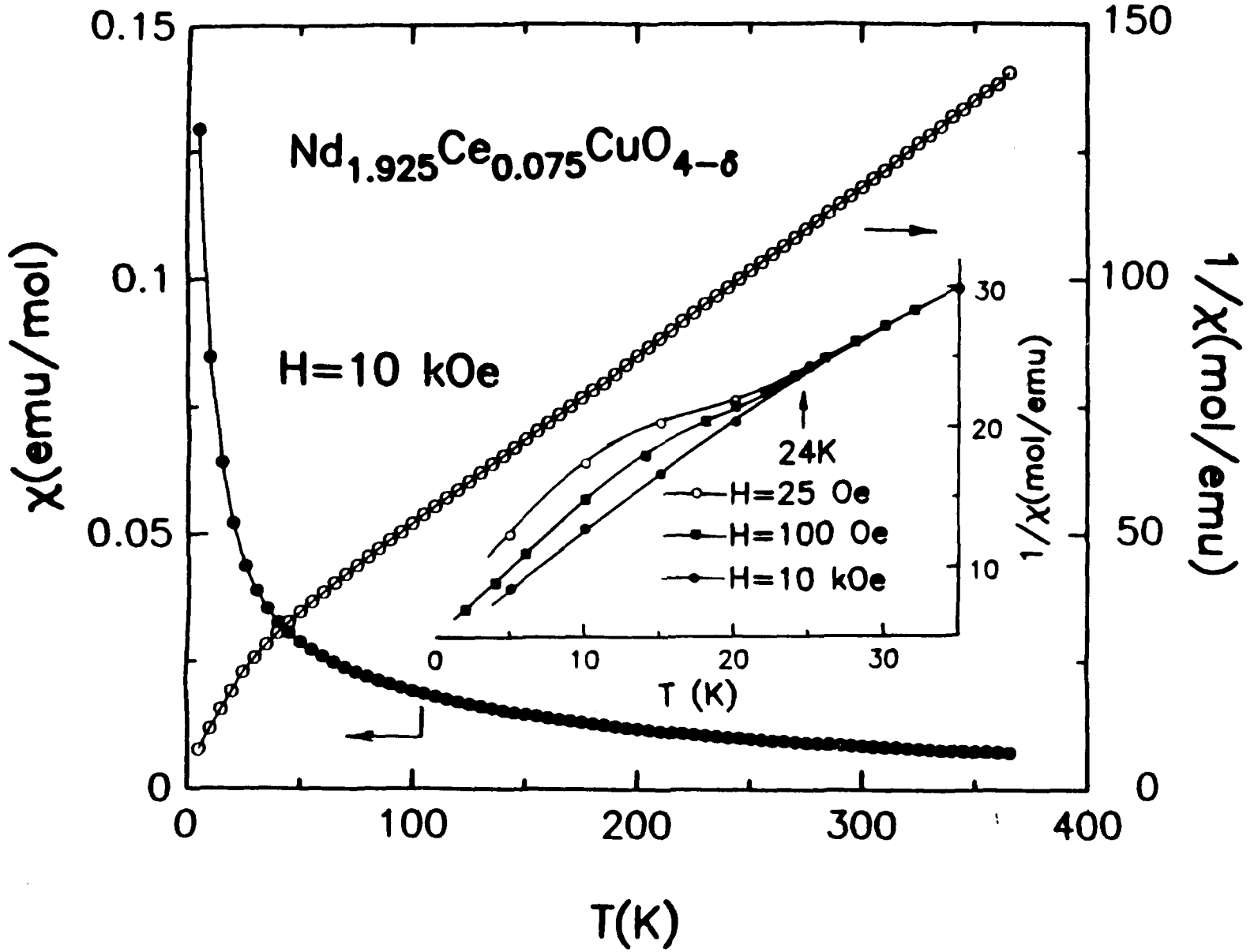
$Nd_{1.925}Ce_{0.075}CuO_{4-\delta}$
H=10 kOe
χ(emu/mol)
1/χ(mol/emu)
T(K)
0.15
0.1
0.05
0
150
100
50
0
0
100
200
300
400
24K
H=25 Oe
H=100 Oe
H=10 kOe
1/χ(mol/emu)
T (K)
30
20
10
0
10
20
30

Fig. 1

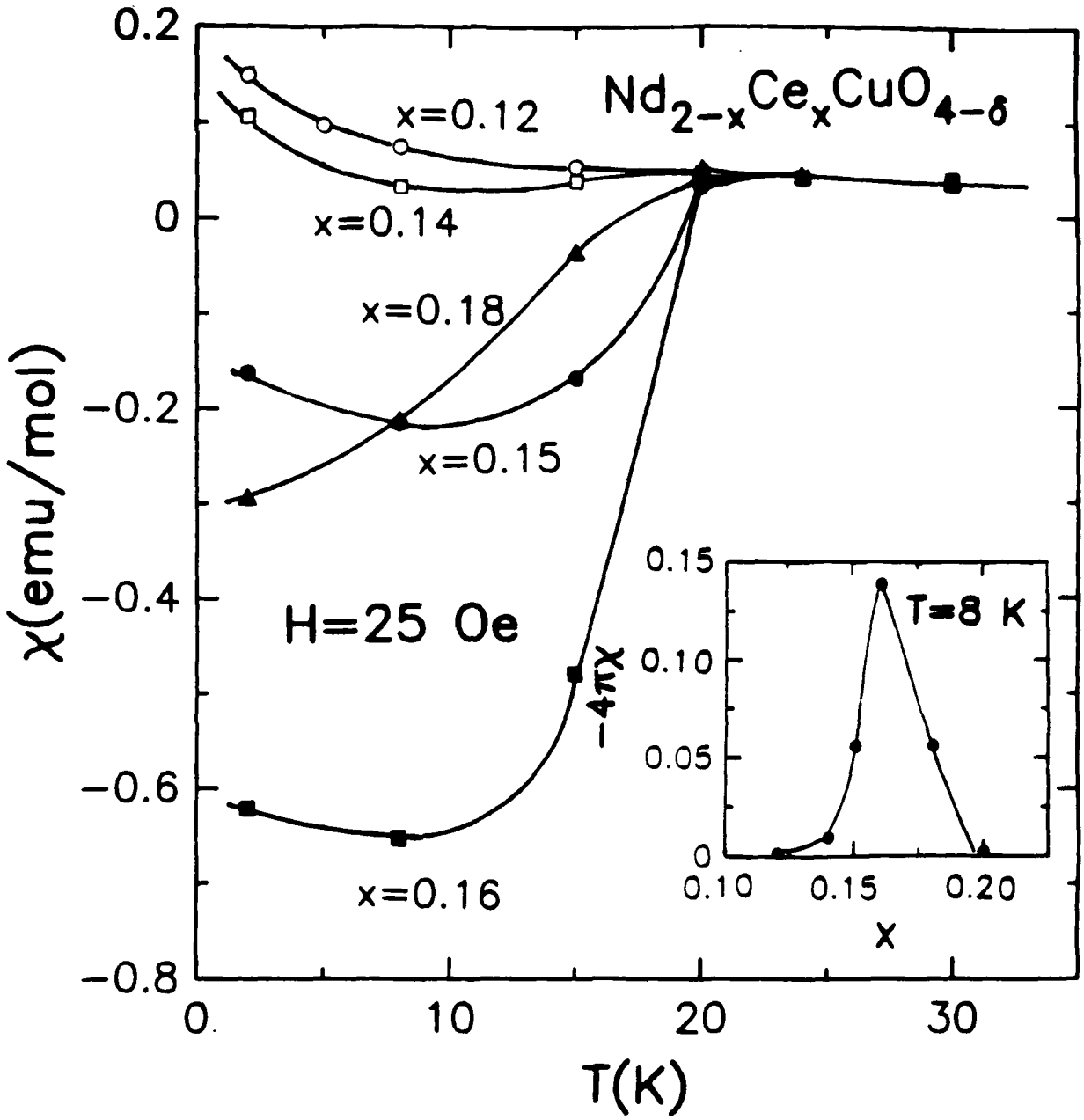
0.2
0
−0.2
−0.4
−0.6
−0.8
χ(emu/mol)
0
10
20
30
T(K)
$Nd_{2-x}Ce_xCuO_{4-\delta}$
x=0.12
x=0.14
x=0.18
x=0.15
x=0.16
H=25 Oe
−4πχ
0.15
0.10
0.05
0
T=8 K
0.10
0.15
0.20
x

Fig. 2

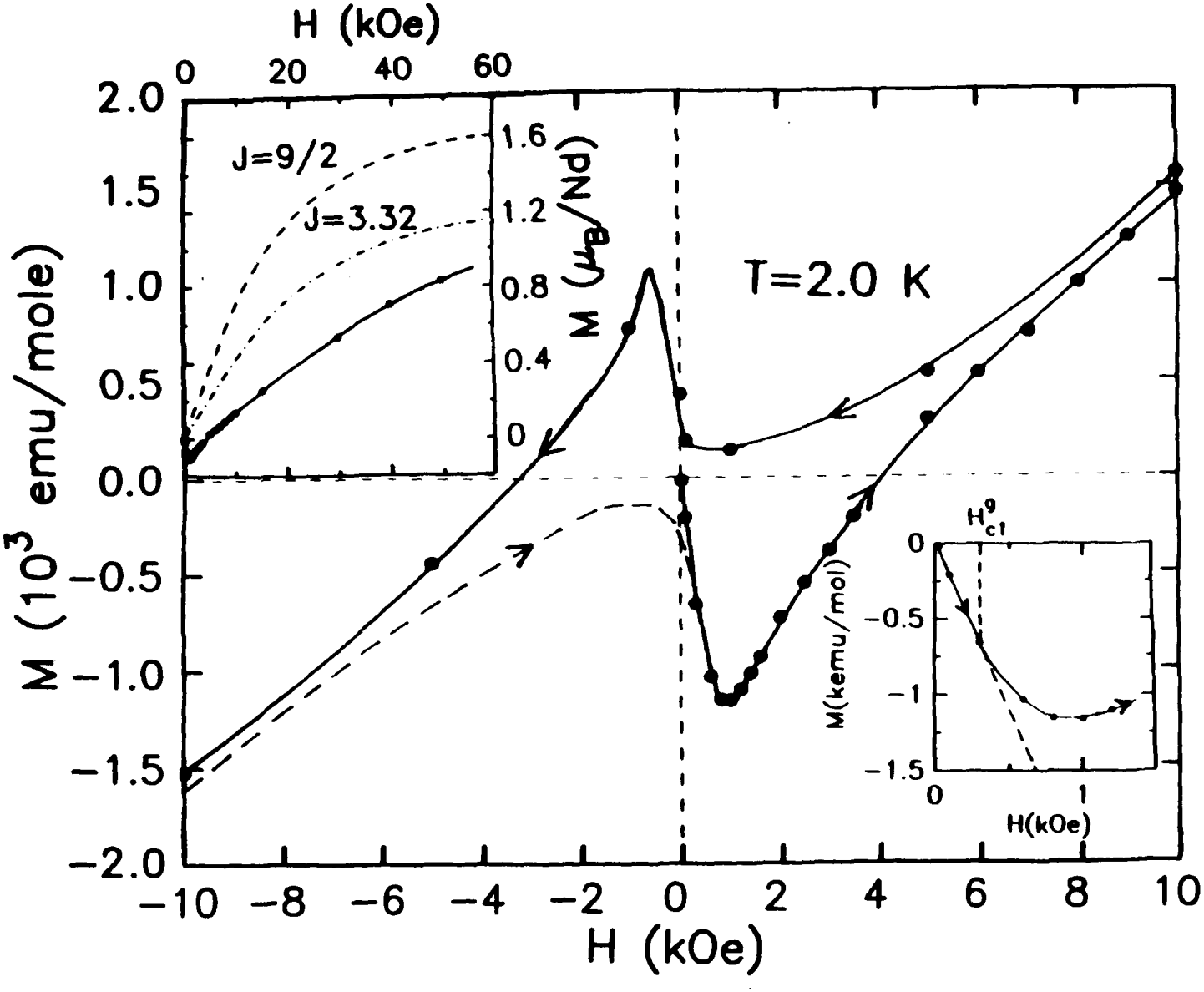
H (kOe)
0
20
40
60
J=9/2
J=3.32
1.6
1.2
0.8
0.4
0
M (μ_B/Nd)
T=2.0 K
H^9_{c1}
0
-0.5
-1
-1.5
M(kemu/mol)
0
1
H(kOe)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
M (10^3 emu/mole)
-10
-8
-6
-4
-2
0
2
4
6
8
10
H (kOe)

Fig. 3

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